Effects of Temperatures and Rainfall Variability on the Abundance and Diversity of Caelifera (Insecta, Orthoptera) in Three Natural Environments in the Mzab Valley, Septentrional Sahara (Algeria)

Youcef Zergoun, Laboratoire des Bioressources Sahariennes: Préservation et Valorisation, Département des Sciences Agronomiques, Faculté des Sciences de la Nature et de la Vie et Sciences de la Terre, Université de Kasdi Merbah, BP 511, 30000 Ouargla, Algeria, and Département des Sciences Agronomiques, Faculté des Sciences de la Nature et de la Vie et Sciences de la Terre, Université de Ghardaïa, 47000 Ghardaïa, Algeria, **Omar Guezoul, Makhlouf Sekour,** Laboratoire des Bioressources Sahariennes: Préservation et Valorisation, Département des Sciences Agronomiques, Faculté des Sciences de la Nature et de la Vie et Sciences de la Terre, Université de Kasdi Merbah, BP 511, 30000 Ouargla, Algeria, **Noureddine Bouras,** Département de Biologie, Faculté des Sciences de la Nature et de la Vie et Sciences de la Terre, Université de Ghardaïa, 47000 Ghardaïa, Algeria, **and Michael D. Holtz,** Field Crop Development Centre, Alberta Agriculture and Forestry, 5030 - 50 Street, Lacombe, Alberta T4L1W8, Canada

ABSTRACT

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The climatic condition is assumed as the main factor responsible for development and survival of insects; this investigation was conducted to study the responses of Caelifera to temperatures and precipitation variations during 2017 in three natural environments of Mzab Valley, Ghardaïa, Algeria. A total of 22 grasshopper species were collected, representing four families and eight subfamilies. The subfamily Oedipodinae was the dominant, followed by Pyrgomorphinae and Thrinchinae. Two species: *Sphingonotus rubescens* and *Sphingonotus savignyi* occurred frequently in the three sites. However, only one accidental species, *Eunapiodes* sp. was found. According to our observations, it is clear that the grasshopper diversity was higher in July and August coinciding with the increase in temperature. In such conditions, the precipitation has less influence on species diversity.

Keywords: Algeria, Caelifera, diversity, precipitation, Mzab Valley, temperature

Corresponding author: Noureddine Bouras
Email: noureddine_bouras@yahoo.fr

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More than 28157 species of Orthoptera are distributed worldwide (Cigliano et al. 2018). This order is among the most recognizable and familiar insects, that includes the grasshoppers, locusts and crickets. Although grasshoppers

(Acrididae) are often thought to be associated with grasslands, many species are currently found in tropical forests, shrub-lands, deserts, wetlands, and alpine regions (Song et al. 2018). Grasshoppers are considered as the main important insect that cause damage to crops, comprise an overwhelming proportion of animal biomass and biodiversity, form a major component of food webs, and play important roles in nutrient cycling and plant production in grassland ecosystems (Hawlena and Schmitz 2010).

Several studies confirmed that the recent climatic changes strongly affect the abundance and geographic distribution of insects (Eo et al. 2017) and the richness of pests, particularly Orthoptera (Weiss et al. 2012). In addition, many researches consider Orthoptera as a bioindicators of the climate change (Báldi and Kisbenedek 1997) due to their sensitivity to microclimatic conditions (Zografou et al. 2009). The high temperature can affect directly and indirectly all arthropods by increasing or decreasing their metabolic rates, changing their activity patterns as well as their developmental rates (Zografou et al. 2017).

The abundance of Orthoptera is generally influenced by high temperatures and dry conditions; however, this is not applicable to all species in this group (Capinera and Horton 1989). Weather in the regional scale, particularly the precipitation, is also a critical factor that shapes the population density of locusts (Wysiecki et al. 2011). Lack of rainfall is usually cited as the main factor limiting population increase in acridid inhabiting tropical semiarid and arid areas, while those species occurring in more temperate or marshy areas are favored by years of subnormal rain (Hunter et al. 2001). Climate change also indirectly affects insects by affecting their host plants. The stage of the vegetation can also impact the biological traits of locust, in case of dry vegetation, a phenomenon of gregarization appear and swarm formation (Cisse et al. 2013). In addition, species with low mobility are susceptible to climate change as they may not be able to shift their ranges fast enough to keep up with environmental changes (Eo et al. 2017). A clear understanding of the mechanisms and ability of locusts and grasshoppers to overcome limiting factors in their environment is essential for predicting when and where outbreaks are likely to occur (Hunter et al. 2001). A strong economic loss was signaled and a large amounts of vegetation was destroyed resulting to the invasion of this pests. In general, the grasshopper fauna of the Algerian Sahara, and Mzab in particular, has attracted less attention of entomologists and no serious studies were performed on the pest species diversity of the Mzab Valley. The intention of the present study is to improve knowledge in the diversity of Orthoptera in the Mzab Valley. The objectives of this work was (1) to inventory the species of Orthoptera present in the Mzab Valley, and (2) to compare the attributes of the Caelifera community (abundance, richness and diversity of species).

MATERIALS AND METHODS

Study site.

the Mzab Valley sites locate in the northern Sahara of Algeria (Fig. 1) at an elevation of 530 m above mean sea level, between 32° to 33° north latitude and 3° to 4° east longitude. These sites are characterized by little-evolved type of alluvial wind soils. The climate is Saharan with a mild winter. Sampling and the study of the Caelifera fauna were conducted in three different localities: Wadi N'tissa (Béni Isguen), Wadi Touzouz (Ghardaïa) and Wadi Mzab (El Djaoua, El Atteuf).

Wadi N'tissa (S1): Latitude 32° 45' North, and longitude 3° 66' East. The surface of the site is about 4 ha (rocky terrain). The vegetal cover is mainly composed of *Haloxylon scoparium*, *Peganum harmala*, *Pergularia tomentosa*, *Colocynthis vulgaris*, *Pituranthos chloranthus*, *Atractylis serratuloides*, *Echinops spinosus* and *Androcymbium punctatum*. The sandy and dry areas are characterized by the presence of two Gramineae, *Aristida obtusa* and *Stipagrostis pungens*.

Wadi Touzouz (S2): Latitude 32° 51' North and longitude 3° 60' East. The surface of the collection site is 4 ha (the terrain changes into a rocky bottom with scattered patches of sand). Among the plants, *Haloxylon scoparium*, *Ferula communis*, *Zilla spinosa*, *Cleome Arabica*, *Oudneya Africana*, *Fagonia glutinosa* and *Thymelaea microphylla* were found.

El Djaoua (S3): Latitude 32° 46' North, and longitude 3° 73' East. The surface of the collection site is 4 ha (Rocky and sandy terrain). The vegetation is dominated by *Thymelaea microphylla*, *Oudneya africana*, *Echium pycnanthum*, *Cleome arabica*, and *Stipagrostis pungens*.

Climatic data.

The climatic data was obtained from the Regional Weather Service Station of Ghardaïa (32° 40' N, 3° 80' E; elevation 461 m). Average annual maximum temperature was 28.47 °C; with highest temperature of 40.5 °C in summer and lowest temperature of 6.2 °C in winter. The amount and seasonal precipitation varied greatly among years. From the Regional Weather Service Station database, 2017 annual precipitation was 34 mm.

Grasshopper sampling.

Populations of Caelifera were sampled monthly from January to December 2017. Sampling was performed with quadrats, the most frequently used method for biodiversity studies. The quadrant method defines in each collection site an area of 10000 m^2. Essentially, it consists of laying a 25 m long transect using a string and then placing square 5 m quadrats (25 m^2) along the transect (Gillon 1974). Ten quadrats were sampled at each of the three sites on each sampling date. Grasshoppers collected using the sweep-net were taken to the laboratory for species identification based on identification keys for Orthopteroid from North Africa of Chopard (1943), Dirsh (1965) and keys of the Acridomorpha from North West Africa (Louveaux et al. 2018). Grasshoppers were classified according to modern systematic as used in the Orthoptera species file (Cigliano et al. 2018).

Data analysis.

The data collected from the different sites within the study area were analyzed using the ecological indices. Relative abundance of grasshopper species was estimated by the comparison with the total abundance of all species collected from each site. Species richness was quantified as the total number of species present in each habitat. Two of the most common indices have been used to describe and compare the grasshopper diversity in the prospected sites in 2017: the Shannon-Weaver diversity index (H) and the species evenness. The formula of the Shannon-Weaver diversity index is:

$$H = - \Sigma (ni/N) \times \log_2 (ni/N),$$

where ni is the abundance of the species i in one site and N the total number of species living in the same site. Pielou's evenness (J) is a measure of uniformity. It

describes how evenly the individuals are distributed among the different species:

$$J = H / \log_2 S,$$

where, J = species evenness, H = species diversity and S = number of species (Magurran 2004). The constancy indices were obtained following the formula proposed by Bodenheimer:

$$C = p \times 100 / N,$$

Where p is the number of collections containing the particular species studied and N is the total number of collections carried out. Based on the obtained results, the species were classified as: constant (present in more than 50% of the collections), accessory (present in between 25-50% of the collections) or accidental (present in under 25% of the collections) (Gallo et al. 2002).

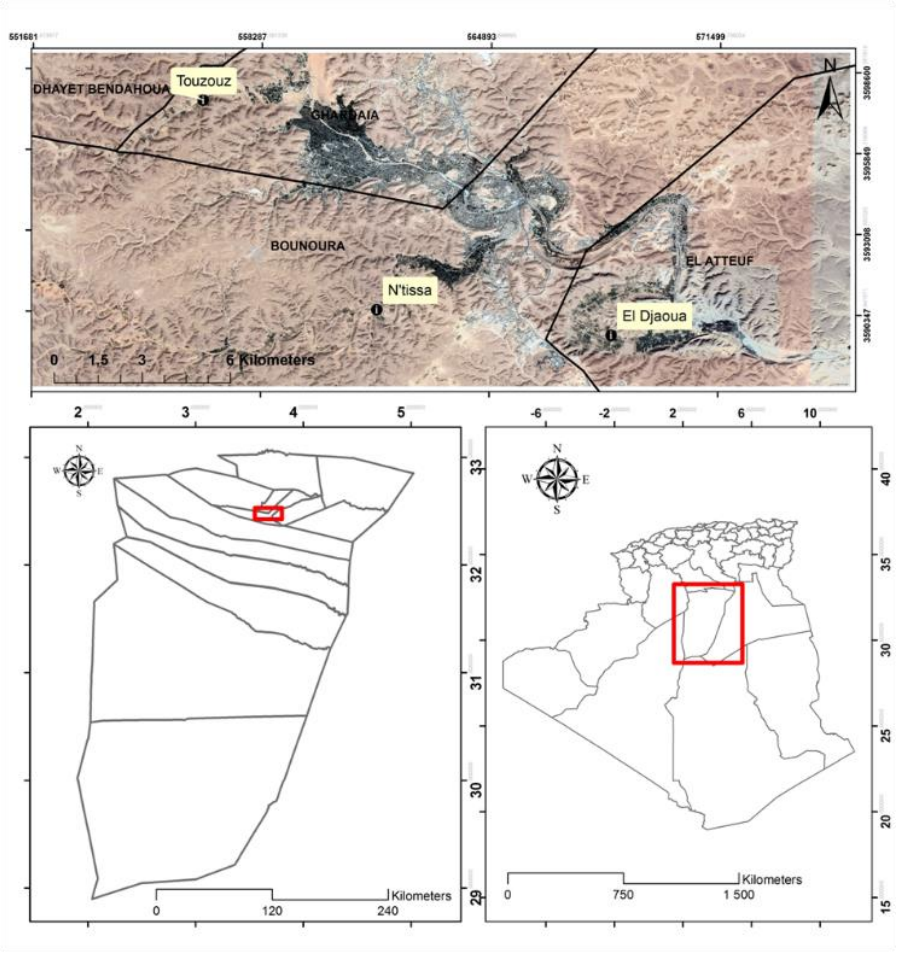

Fig 1. Geographic location of the study sites in the Mzab Valley, Septentrional Sahara, Algeria.

RESULTS

Diversity and abundance of the Caelifera community.

In total, 1385 specimens of grasshoppers were collected during the 12 months. They belonged to 22 species, four families, and eight subfamilies (Table 1). Only 14 species were found in Wadi Mzab, whereas 20 species were found in Wadi N'tissa and 17 species in Wadi Touzouz. From a taxonomic perspective, the Oedipodinae was the most abundant and diverse subfamily (with 12 species), followed by Pyrgomorphinae (with 3 species) and Thrinchinae (with 2 species). There was only one species within Acridinae, Cyrtacanthacridinae, Eremogryllinae, Dericorythinae and Pamphaginae. The abundance of grasshopper species fluctuated between sites (Table 1). *Sphingonotus rubescens* was broadly distributed in the three natural environments [29.74% (S1), 28.82% (S2) and 31.60% (S3)], and *Sphingonotus rubescens* exhibited very high population abundance, representing 29.96% of the total grasshopper relative abundance. *Sphingonotus paradoxus* occurred in Wadi Touzouz but was not found in Wadi N'tissa and Wadi Mzab. Some species were only distributed on rocky terrain. For example, *Tuarega insignis*, *Dericorys millierei* and *Eunapiodes* sp. occurred only in Wadi N'tissa. Nevertheless, *Eunapiodes* sp. (0.36%), *Sphingonotus pachecoi* (0.91%), and *Schistocerca gregaria* (0.91%) had the lowest numbers.

The recorded species were divided into constancy classes (Table 1): in Wadi N'tissa 7 species (35%) are constant species (C), 12 species (60%) are accessory species (Ac) and one species (5%) is an accidental species (Acc). In Wadi Touzouz 8 species (47.06%) are constant species (C) and 9 species (52.94%) are accessory species (Ac). The most numerous are the constant species (C) in Wadi Mzab: 9 species (64.28 %), and 5 species (35.71%) are accessory species (Ac).

Wadi N'tissa was most diversified (2.49%) with the highest abundance of Caelifera (548), Wadi Touzouz was least diversified (2.34%) with low abundance (451) and Wadi Mzab was least diversified (2.23%) with low abundance (386) of Caelifera. Grasshopper abundance was positively related with species diversity (Table 2). High values of evenness ($0.82 < J < 0.84$) indicated that the Orthoptera community was evenly distributed at all sites.

Species diversity.

During the study period, the highest Shannon-Weaver diversity index (2.45 bits) was observed in August (maximum temperature of 40.3 °C, minimum temperature of 27 °C, average temperature of 33.7 °C) and lowest (0.67 bits) in January (maximum temperature of 14.9 °C, minimum temperature of 4.8 °C, average temperature of 9.8 °C) in Wadi N'tissa. From Wadi Touzouz the highest Shannon-Weaver diversity index (2.27 bits) was observed in August (maximum temperature of 40.3 °C, minimum temperature of 27 °C, average temperature of 33.7 °C) and lowest (0.95 bits) in December (maximum temperature of 16.7 °C, minimum temperature of 6.2 °C, average temperature of 11.5 °C). In Wadi Mzab the highest Shannon-Weaver diversity index (2.13 bits) was observed in April (maximum temperature of 27.7 °C, minimum temperature of 14.9 °C, average temperature of 21.3 °C) and lowest (1.21 bits) in February (maximum temperature of 20.6 °C, minimum temperature of 8.8 °C, average temperature of 14.7 °C). Temperature effect on the Shannon-Weaver diversity index (H) of Caelifera in the three study areas is given in Fig. 2.

Table 1. Listing, abundance (%) and constancy of Caelifera species in natural environments at three localities from the Mzab Valley, northern Sahara (Algeria) during 2017

Family	Subfamily	Species	S1	S2	S3
Acrididae	Acridinae	*Truxalis nasuta* (Linnaeus, 1758)	3.28 (C)	2.21 (Ac)	3.37 (C)
	Cyrtacanthacridinae	*Schistocerca gregaria* (Forskål, 1775)	0.91 (Ac)	1.10 (Ac)	2.07 (Ac)
	Eremogryllinae	*Notopleura saharica* (Krauss, 1902)	1.46 (Ac)	3.10 (Ac)	4.14 (Ac)
	Oedipodinae	*Acrotylus longipes* (Charpentier, 1845)	6.20 (Ac)	7.32 (Ac)	10.88 (Ac)
		Acrotylus patruelis (Herrich-Schäffer, 1838)	3.83 (Ac)	-	-
		Hyalorrhipis calcarata (Vosseler, 1902)	1.46 (Ac)	-	-
		Sphingoderus carinatus (Saussure, 1888)	3.28 (Ac)	2.44 (Ac)	5.18 (C)
		Sphingonotus azurescens (Rambur, 1838)	4.01 (Ac)	2.66 (Ac)	
		Sphingonotus obscuratus lameerei (Finot, 1902)	3.83 (Ac)	2.88 (Ac)	2.33 (Ac)
		Sphingonotus octofasciatus (Serville, 1839)	5.29 (C)	3.32 (C)	1.81 (Ac)
		Sphingonotus pachecoi (Bolivar, 1908)	0.91 (Ac)	1.33 (Ac)	2.84 (C)
		Sphingonotus paradoxus (Bei-Bienko, 1948)	-	4.65 (C)	-
		Sphingonotus rubescens (Walker, 1870)	29.74 (C)	28.82 (C)	31.60 (C)
		Sphingonotus savignyi (Saussure, 1884)	13.32 (C)	19.29 (C)	16.32 (C)
		Vosseleriana fonti (Bolivar, 1902)	2.74 (Ac)	13.30 (Ac)	-
Dericorythidae	Dericorythinae	*Dericorys millierei* (Bonnet & Finot, 1884)	1.09 (Ac)	-	-
Pamphagidae	Pamphaginae	*Eunapiodes* sp. (Bolivar, 1907)	0.36 (Acc)	-	-
	Thrinchinae	*Tmethis cisti* (Fabricius, 1787)	-	5.76 (C)	4.14 (C)
		Tuarega insignis (Lucas, 1851)	2.55 (Ac)	-	-
Pyrgomorphidae	Pyrgomorphinae	*Pyrgomorpha cognata* (Krauss, 1877)	5.66 (C)	2.88 (C)	5.44 (C)
		Pyrgomorpha conica (Olivier, 1791)	3.83 (C)	2.66 (C)	4.14 (C)
		Tenuitarsus angustus (Blanchard, 1836)	6.20 (C)	8.20 (C)	5.70 (C)

(-): absent species. S1: Wadi N'tissa (Béni Isguen), S2: Wadi Touzouz (Ghardaïa), S3: Wadi Mzab (El Djaoua, El Atteuf). (C): Constant, (Ac): Accessory, Acc: Accidental.

Table 2. Diversity parameters for three localities from the Mzab Valley, northern Sahara (Algeria) during 2017

Index	Wadi N'tissa	Wadi Touzouz	Wadi Mzab
Species number	20	17	14
Species diversity (H)	2.49	2.34	2.23
Species evenness (J)	0.83	0.82	0.84

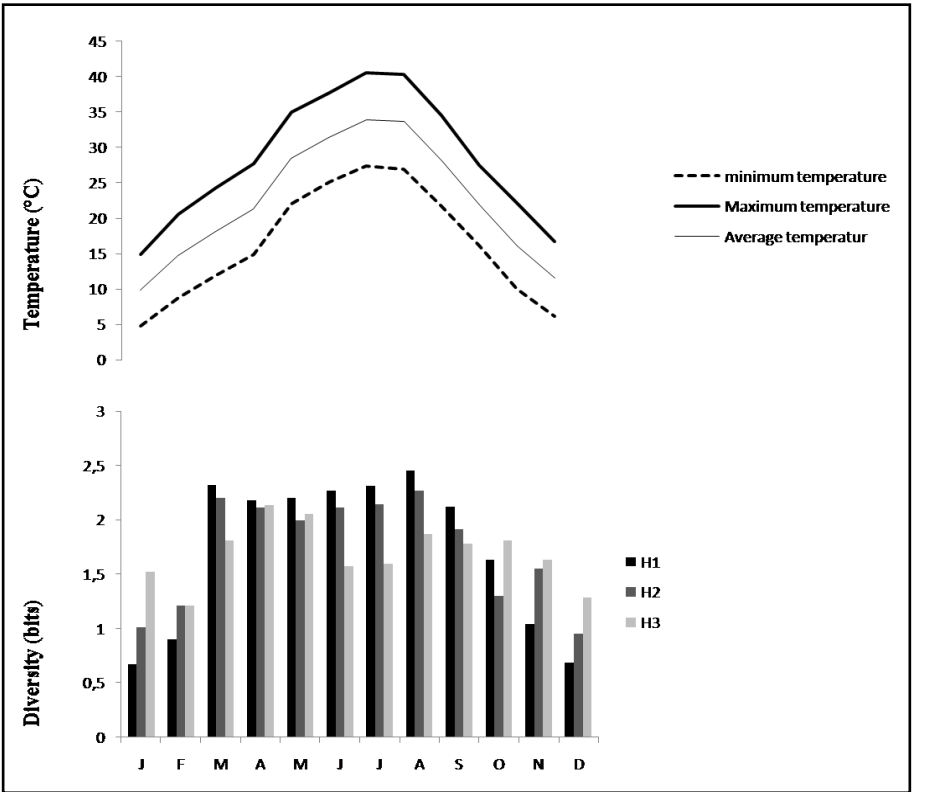

Fig. 2. Effect of temperature on Caelifera species diversity (H) in three localities from the Mzab Valley, northern Sahara, Algeria (during 2017). H1-H3 : Shannon-Weaver diversity index (H) of Wadi N'tissa (Béni Isguen), Wadi Touzouz (Ghardaïa) and Wadi Mzab (El Djaoua, El Atteuf), respectively.

Effect of precipitation on species diversity.

The study of precipitation effect (P) on species diversity (H) of Caelifera shows that the highest Shannon-Weaver diversity index (2.45 bits) was observed in August (P = 0 mm) and lowest (0.67 bits) in January (P = 1 mm) in Wadi N'tissa. From Wadi Touzouz the highest Shannon-Weaver diversity index (2.27 bits) was observed in August (P = 0 mm) and lowest (0.95 bits) in December (P = 0 mm). In Wadi Mzab the highest Shannon-Weaver diversity index (2.13 bits) was observed in April (P = 0 mm) and lowest (1.21 bits) in February (P = 0 mm). Effect of precipitation on species diversity (H) of Caelifera in the three study areas is given in Fig. 3.

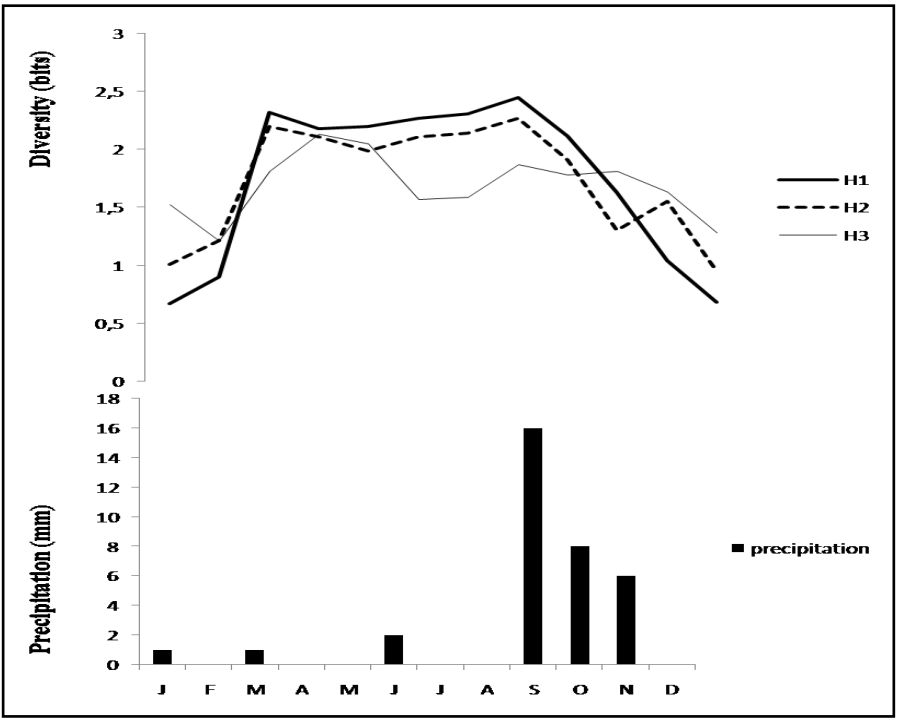

Fig. 3. Effect of precipitation on Caelifera species diversity (H) in three localities from the Mzab Valley, northern Sahara, Algeria (during 2017). H1-H3 : Shannon-Weaver diversity index (H) of Wadi N'tissa (Béni Isguen), Wadi Touzouz (Ghardaïa) and Wadi Mzab (El Djaoua, El Atteuf), respectively.

DISCUSSION

Species richness of grasshoppers noted in this study was about 22 species; however, Zergoun (1991) and Babaz (1992) noted 17 and 16 species, respectively, in the same area, Mzab Valley. Previous studies conducted by Zergoun (1991, 1994), (Babaz 1992) and Yagoub (1995) reported that Oedipodinae was the most abundant in this area. Zergoun (1991, 1994) found *Sphingonotus rubescens* particularly dominant in natural environments of the Mzab Valley. According to Otte (1984), band-winged grasshoppers (subfamily Oedipodinae) was abundant only in areas with relatively sparse ground cover. In this study, they were most common on rocky terrain. Rock cover seems to have an even greater positive influence on Orthoptera (Zografou et al. 2017). Rocks are important to Orthopterans aiding in thermoregulation as well as providing shelter (Chappell 1983). Members of Oedipodinae and Thrinchinae subfamilies, preferring warm, dry habitats with sparse grass cover, were only found in desert and mountain rangelands (Sun et al. 2015). In

the prospected areas, the diversity was stable as also noted by Aprile (2013) indicating that these zones are the most adapted areas that offer the best conditions for their survival. Only one accidental species, were found, *Eunapiodes* sp. Diversity of Caelifera fluctuates with the seasons. They are abundant for only a few months and absent or rare during the rest of the year. When we compare different months for Caelifera species diversity (H) it is clear that diversity was at a maximum in July and August and lowest in January, February and December. The results were similar to the finding of Zergoun (1994). According Capinera and Horton (1989), warm dry weather is positively associated with grasshopper and locust densities in several areas of the world. In the present study, the lower diversity registered in winter could be related to the weather patterns and decreased vegetal diversity at these sites. According to De Wysiecki (2000), composition and structure of vegetation likely influence habitat selection among grasshoppers. From Fig. 2, it is clear that the diversity of Caelifera is affected by variation in the pattern of rainfall in different months of 2017. From these results, it appears that the grasshopper diversity was higher in July and August concurrent with the decrease in rainfall. In such conditions, precipitation has no influence. Smith and Holmes (1977) suggested that densities of *Melanoplus sanguinipes* and *Camnula pellucida* in Alberta were positively related to summer temperatures and negatively related to amount of precipitation during the previous August and September. In the United States, the populations case of *Dissoteira longipennis* showed rapid increases in numbers following periods of drought, subsiding in numbers during periods of above-average rainfall (Wakeland 1958). Contrary to our results, Usmani et al. (2010) reported that rainfall also affects diversity in India. According to Hunter et al. (2001), rainfall seems to be a major regulator of Acridid populations in Australia. Precipitation and drought driven effects on food quality and quantity are important for grasshopper population dynamics (Joern et al. 2012). According to Jonas et al. (2015), weather acts on grasshopper populations indirectly by altering host plant species composition, availability and quality.

The present study was conducted to estimate abundance, diversity, constancy and the effect of temperature and precipitation on grasshopper species in Mzab Valley, Ghardaïa, Algeria, during 2017. The grasshoppers were collected from study sites with the majority of specimens belonging to sub-family Oedipodinae (54.54 %) dominated by genus *Sphingonotus*. The family Acrididae contained most collected species (15) followed by Pyrgomorphidae with 3 species. Data on species abundance showed that *Sphingonotus rubescens* was dominant in the three sites. Fluctuation in temperature is vital roles in determining the abundance of Caelifera fauna from Mzab Valley. It is obvious to see that the diversity of Caelifera is affected by temperature variations in different months. It appears that the grasshopper diversity was higher in July and August when temperatures increase. In these months, precipitation is very low or absent. However, the results of this study cannot be generalized to all areas or grasshopper assemblages. Further research is required on the physiological and behavioral responses of dominant species according to climate parameters.

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RESUME

Zergoun Y., Guezoul O., Sekour M., Bouras N. et Holtz M.D. 2018. Effets des températures et de la variabilité des précipitations sur l'abondance et la diversité des *Caelifera* (insecte, Orthoptère) dans trois environnements naturels de la Vallée de Mzab, Sahara Septentrional (Algérie). Tunisian Journal of Plant Protection 13 (2): 217-228.

La condition climatique est supposée être le principal facteur responsable du développement et de la survie des insectes; cette étude a été menée pour étudier les réponses de *Caelifera* aux variations de températures et de précipitations en 2017 dans trois environnements naturels de la Vallée de Mzab, Ghardaïa, Algérie. Au total, 22 espèces de sauterelles ont été recueillies, représentant 4 familles et 8 sous-familles. La sous-famille *Oedipodinae* est la plus dominante, suivie des *Pyrgomorphinae* et des *Thrinchinae*. Deux espèces: *Sphingonotus rubescens* et *Sphingonotus savignyi* sont les plus fréquentes sur les trois sites. Cependant, une seule espèce accidentelle, *Eunapiodes* sp., a été trouvée. Selon nos observations, il est clair que la diversité des sauterelles était plus élevée en juillet et août, ce qui coïncidait avec l'augmentation de la température. Dans de telles conditions, les précipitations ont moins d'influence sur la diversité des espèces.

Mots clés: Algérie, Caelifera, diversité, précipitations, température, Vallée du Mzab

ملخص

زرقون، يوسف وعمر قزول ومخلوف سكور ونورالدين بوراس ومايكل هولتز. 2018. تأثيرات درجات الحرارة وتقلبات تساقط الأمطار على وفرة وتنوع Caelifera (حشرات، مستقيمات الأجنحة) في ثلاث بيئات طبيعية في وادي مزاب، الصحراء الشمالية (الجزائر).

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أجريت هذه الدراسة لتقدير وفرة وتنوّع وانتظام وتأثير درجة الحرارة والتساقط على مستقيمات الأجنحة تحت رتبة *Caelifera* في عام 2017 في ثلاث بيئات طبيعية في وادي مزاب، غرداية (الجزائر). تمّ جمع 22 نوعا من الجراد ، تمثّل أربع فصائل وثمانية تحت فصائل. كانت فصيلة *Oedipodinae* المهيمنة، تلتها *Pyrgomorphinae* و *Thrinchinae*. تمّت ملاحظة أن *Sphingonotus rubescens* و *Sphingonotus savignyi* هما نوعان شائعان في جميع المواقع الثلاثة. على مستوى المواقع الثلاثة، تمّت ملاحظة أنواع ثابتة وأخرى ملحقة. كما وجد نوع واحد عارض وهو *Eunapiodes* sp. أظهرت النتائج بوضوح أن تنوع الجراد كان أعلى في شهريْ يوليو وأغسطس، بالتزامن مع الزيادة في درجة الحرارة. في مثل هذه الظروف ، كان للتساقط أقل تأثيرا على تنوع الأنواع.

كلمات مفتاحية: الجزائر، انتظام، تساقط، تنوع، درجة حرارة، وادي مزاب، *Caelifera*

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